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DIGITALISATION AND ELECTRIFICATION IN SYMBIOSIS

FUTURE WATCH

gaia

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CONTENT

1. INTRODUCTION

Executives in the energy sector and industry alike are striving to meet ever higher sustainability demands while simultaneously attempting to understand how fundamentally and in what ways digitalisation will bring changes to their business. At the same time, political decision-makers across Europe are making investment decisions with lasting repercussions for our future, as the Green Deal is put into action.

Three major changes are revolutionising the energy system. One of them is related to making energy production climate-friendly. The second is linked to the new role of energy users themselves in producing and storing energy. Finally, the share of electricity in energy use is rising rapidly. All these developments will have a significant impact on society, profoundly affecting our food system, manufacturing industries, natural environment, private consumption, and public sector.

The aim behind this white paper is to equip decision-makers with vital insight and examples for shaping tomorrow's low-carbon digital society and business ecosystems at the nexus of digitalisation and electrification. It was prepared by Gaia Consulting for Business Finland and Technology Finland.

DIGITALISATION AND ELECTRIFICATION JOINTLY CREATE IMPETUS FOR A LOW-CARBON SOCIETY – THE TWO PROPEL EACH OTHER TOWARD THE FUTURE

THE GROWING SOCIETAL IMPACT OF DIGITALISATION

Societies are increasingly driven by data and digitalisation. While various uncertainties complicate evaluation of the ICT sector's total electricity consumption, with estimates varying between 4% and 10% of world electricity demand[1], the figures are large by any metric: the ICT sector is estimated to represent 3–5% of global greenhouse gas emissions already[2]. Digital technology's use accounts for more than 50% of its energy consumption, comparable to the energy that goes into producing the equipment[3], and entertainment accounts for by far the largest proportion of that use. Online videos alone are expected to generate 80% of world data flows by 2022[4].

However, digitalisation also holds vast potential to move us toward low-carbon societies. Its potential for changing the way we generate and use energy (and other resources) can hardly be overstated. Digitalisation enables a clean-energy revolution. It is key to efficient, flexible, and resilient energy infrastructure with an increasing share of renewables and to a more reliable power system that has fewer outages and also lower operation and maintenance costs[5]. This is particularly important because power production from renewable sources is intermittent in nature and demands high flexibility from the entire energy system[6].

Electricity is at the heart of modern economies and at the core of interlinked energy systems. Societies are driven by electrification, a transformation that radically increases demand for electricity and various power-to-*x* pathways, by which electricity is transformed and converted for other usable energy-carriers. Production, storage, and logistics for such products as hydrogen, methane, ammonia, and electro fuels are bound up with our electricity, heating, and cooling networks. For large-scale geographically distributed systems and their complex interconnections, operations require efficient modelling and advanced data flows. True mastery of energy systems for the future requires optimisation in multiple time frames, from seconds to months and years, in all of which digitalisation and data must be strongly coupled with energy-sector activities. Decarbonised electricity presents considerable opportunities for reducing CO_2 emissions through electricity-based fuels such as hydrogen and synthetic liquid fuels.

All this will have a huge impact on all aspects of society and the economy. The digital revolution is expected to disrupt and transform transportation, construction, industry, and other sectors and can help substantially reduce their emissions[7]. However, the greatest potential of digitalisation lies in its ability to break down boundaries between sectors, enabling integration across entire systems.

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[1] Source: Finnish Ministry of Transport and Communications. 'Toward climate and environmental objectives with ecologically sustainable digitalisation: Final report of the working group preparing a climate and environmental strategy for the ICT sector in Finland'. Finland, 2020 (in Finnish).
[2] *Ibid*.
[3] Source: Shift Project. 'Lean ICT – towards digital sobriety: Report of the working group directed by Hugues Ferreboeuf for the think tank the Shift Project', 2019, at https://theshiftproject.org/wp-content/uploads/2019/03/Lean-ICT-Report_The-Shift-Project_2019.pdf (accessed on 11.2.2021).
[4] Source: Finnish Ministry of Transport and Communications. 'Toward climate and environmental objectives with ecologically sustainable digitalisation: Final report of the working group preparing a climate and environmental strategy for the ICT sector in Finland'. Finland, 2020 (in Finnish).
[5] Source: DIGITALEUROPE. 'Digital contribution to delivering long-term Climate Goals', 5.2.2020, at https://www.digitaleurope.org/resources/digital-contribution-to-delivering-long-term-climate-goals/ (accessed on 11.2.2021).
[6] Source: 'Status of power system transformation 2019', from the Web site of the International Energy Agency, at https://www.iea.org/reports/status-of-power-system-transformation-2019 (accessed on 25.1.2021).
[7] Source: 'Digital contribution to delivering long-term Climate Goals' (see Note 5).

2. DIGITALISATION AND ELECTRIFICATION AS MASSIVE DISRUPTION SOURCES

2.1 Key future disruptions

For 2030 and beyond, a digital energy system can underpin our low-carbon society. The decreasing role of fossil fuels, growing utilisation of renewables, a rise in decentralised production, and new solutions for electricity storage and transmission are already fundamentally altering the energy sector. Among the questions to be resolved for the future are how we will produce energy; in which forms we will use, transmit, and store it; and how the energy system is to be controlled and managed.

THE FUTURE RESTS ON A SCENARIO OF SEVERAL KEY DISRUPTIONS:

DIGITALISATION AS ONE OF THE MOST POWERFUL ACCELERATORS TO CLIMATE SOLUTIONS

Digitalisation is among the most potent accelerators of climate solutions. It has remarkable potential to influence multiple sectors and disrupt whole societies[8]. Digital services' potential to reduce energy and material use economy-wide equates to 10 times their footprint. In this vision, they directly enable a third of the emissions reductions needed by 2030[9].

Digital technologies and the data economy provide an opportunity for not just radical business and service disruptions but also directly scalable climate solutions. Rather than incremental improvements, they permit rapid scaling and self-reinforcing climate action[10]. Some mechanisms of digital disruption for a low-carbon society are new ways of transmitting data, edge intelligence, quantum computing, the Internet of things (IoT), advanced analytics and AI, digital platforms, digital twins, blockchain technology, virtual and augmented reality, and solid cyber-security.

THE SUPER-POWER OF MAKING ENERGY SYSTEMS ANTIFRAGILE AND FLEXIBLE

Interplay of the digital domain and energy will usher in a new reality: an efficient, flexible, and antifragile energy system with renewables, a highly reliable power system, and lower costs via real-time holistic optimisation of demand and supply. Digitalisation and data play a major role in rendering traditional energy systems highly flexible while also enabling large-scale electrification. Agile, rapidly reacting digital mechanisms afford optimising and balancing energy supply and demand in new ways, to form innovative services. Connectivity will be a key enabler, supporting decision-making that is driven by a fuller picture rather than siloed. Smart resource and energy choices will be commonplace within a decade.

Future energy systems play by the rules of digitality. A new playing field and new 'rules of the game' will emerge – challenging the existing energy markets and enabling a low-carbon transformation. While exponential development has been the primary business model in the digital industry for decades, the next 10 years will

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[8] Source: Exponential Roadmap Initiative (with lead authors J. Falk and O. Gaffney). *Exponential Roadmap 1.5.1.* Sweden: Future Earth, January 2020.
[9] Ibid.
[10] Ibid.

see this pace of change get adopted by energy systems. Opportunities arise where the two domains' short- and long-term investments and interests meet.

Sound cyber-security is critical. Secure future energy systems demand comprehensive attention to security, from the early stages of system design all the way to continuing operation.

MATCHING OF ENERGY SUPPLY AND DEMAND – PLAIN GOOD SENSE

Sectoral integration interweaves energy supply and demand. The greatest potential for digitalisation is found in its ability to break down boundaries between energy sectors, thereby enabling integration across various systems. This integration, encompassing industry, facilities, and mobility, provides opportunities for enhancing energy- and material-efficiency while decreasing the need for primary energy and investments in new energy-production capacity. Synthesis mechanisms and data flows between physical sources of energy production are crucial, as is connecting consumption with efficient energy markets.

Interconnectivity enables optimising supply and demand in real time. In large-scale electrification of society, supply with both real-time interconnection and quick response to demand are vital. Demand, supply, and storage resources will be handled automatically in the future energy system. Use of data provides an opportunity for active consumers to make insightful decisions and for organisations to provide services that apply new business models (e.g., to fund energy-related investments). Flexible conversion of energy, hybrid energy systems, new clean carriers of energy, and cross-sector energy storage all are part of the system.

A DIGITAL ENERGY SYSTEM WILL DRIVE THE LOW-CARBON SOCIETY FOR 2030 AND BEYOND

2.2 Drivers for the energy revolution

Digitalisation and the data economy are already pushing the clean-energy revolution forward, with diverse interlinkages that include renewables-driven electrification of societies, sectoral integration that forges links between energy-consuming and producer sectors, local energy production and storage that match supply with demand, and effective energy markets integrating a wide range of actors (see Table 1).

MULTI-SECTOR INTEGRATION WILL DECARBONISE THE ENTIRE ENERGY SYSTEM, ACROSS ENERGY-CARRIER, INFRASTRUCTURE, AND CONSUMPTION-SECTOR BOUNDARIES

Table 1. ***Weapons in the energy revolution, in the context of a low-carbon society and digitalisation***

	HOW THIS SUPPORTS LOW-CARBON SOCIETY	WHAT DIGITALIZATION ENABLES	EXAMPLES
ELECTRIFICATION OF SOCIETIES	Electrification of societies builds on flexible energy systems that enable strong growth in use of renewables for low-carbon energy production. Flexibility also entails integrating power-to-*x* and storage concepts into the energy system.	Digitalisation and data enable flexibility in all portions of the energy system. The energy landscape of the future comprises optimal use of production, consumption, and storage systems that offers stability for the grids. This optimised utilisation of production and storage systems enables maximising renewable production and waste-heat recovery. Also important for grid stability are simultaneous aggregation of controllable devices for demand response and virtual-power-plant concepts. Handling the demand side – by aggregating and controlling distributed energy sources – while managing geographically decentralised power production requires active inter-system data flows and sufficient processing capacity. Accurate adaptive and predictive algorithms are essential for optimisation in such a versatile system and for minimising disparities between production and demand.	Optimal utilisation of production and storage systems Demand response and virtual-power-plant concepts that combine demand-side management and local energy production Demand-side management via diverse controllable loads throughout all consumption sectors Intelligent management of a complex electricity grid and varied district-heating networks Better matching of production with demand, via improved forecasting
SECTORAL INTEGRATION	Multi-sector integration provides opportunities to improve energy- and material-efficiency both and to decrease the need for primary energy and associated investments.	Sectoral integration seamlessly connects the energy-consuming sectors – buildings, transport, and industry – with the energy sector by means of smart infrastructure and greater penetration of renewable energy. Accordingly, it allows optimising the energy system as a whole . It creates opportunities for higher energy- and material-efficiency, partly thanks to energy-system planning and operation that is co ordinated 'as a whole', across multiple energy-carriers, types of infrastructure, and consumption sectors . Digitalisation and data provide for efficient utilisation of the available energy resources, handled sector-specifically and with improved detection of system inefficiencies. They afford effective integration via real-time measurement of processes and energy use – by means of advanced data analytics, including AI.	Power-to-hydrogen/methane solutions that establish strong connections for transportation and industries that exploit electricity and gas systems Power-to-heat solutions coupling smart grids with heating networks Electric vehicles offering electricity-grid stability and storage mechanisms

LOCAL ENERGY PRODUCTION AND STORAGE MATCHING DEMAND AND SUPPLY	In combination with nearby storage systems, waste-heat recovery, and demand-side management, local energy production enables efficient clean-energy communities with a large share of renewables.	Digitalisation promotes the evolution of clean-energy communities that utilise locally produced renewable energy near the points of consumption and promotes efficiency through waste-heat recovery systems. Efficient operation of clean-energy communities requires active co-operation with energy markets and dynamic control of local micro-grids connected with large-scale energy transmission and production systems. Evolution of digitalisation and the data economy eliminates bottlenecks related to these real-time system operations and to connectivity (with regional electricity grids, gas and district-heating networks, etc.). Developing versatile clean-energy communities is another important element of system flexibility.	Energy-system-connected clean-energy communities with a high proportion of their energy needs met through renewables Distributed storage solutions combined with local production and demand-side management Waste-heat recovery systems offering surplus energy for local heating networks
WELL-FUNCTIONING ENERGY MARKETS	Effective energy markets afford real-time energy-efficiency and resource-efficiency across all sectors. They support investments both in local and distributed renewable energy production and in demand-side management.	Both smaller entities (active individuals etc.) and utility-scale producers will offer energy production to the markets. The same applies for the aggregation of controllable loads to be used in the markets that the transmission-system operator provides for grid stability. As the actors involved in the markets are divided into smaller units, the data flow increases, thus necessitating more processing capacity. Lowering the barrier to entry, data platforms and hubs make the markets accessible to new operators, with several business models and diverse energy-resource and production portfolios. Digitalisation-based technologies enable physical and economic connections between local and central energy markets. The technologies enable bundling the resources with effective modular and scalable services suited to the relevant local requirements. These resources can be more effectively utilised in the energy markets.	Transparency and traceability of energy streams, all the way from production to consumption and recovery Data platforms and hubs that enable new business models Deep integration of sectors – including aggregation of diverse energy resources and control of distributed production portfolios

2.3 Digital drivers for a low-carbon society

Mature digital technologies such as mobile Internet solutions, cloud computing, Big Data, apps, smart devices, and first-generation industrial automation offer foundations for efficiency gains in all industries. Cyber-security is critical in securing the operation of the critical infrastructure. The next digital technologies in the pipeline can be expected to exploit advances in data transmission, quantum computing, edge intelligence, IoT systems, advanced analytics and AI, digital platforms, blockchain backbones, digital twins, immersive user experiences (e.g., from virtual and augmented reality), and attention to cyber-security (see Figure 2). These may enable significant emission reductions before 2030[11].

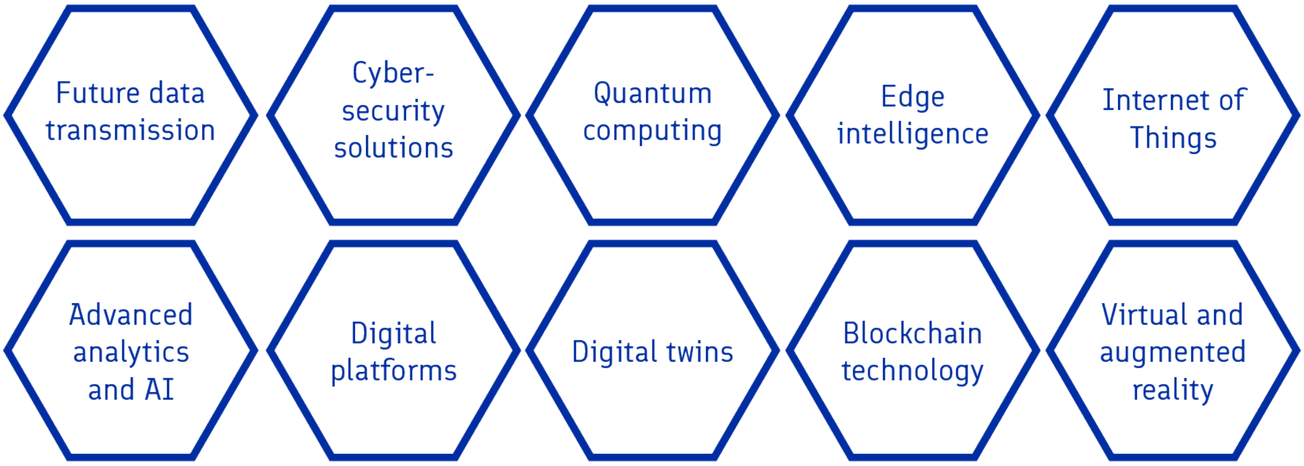

Figure 1. ***Digital drivers for a low-carbon society.***

NEW DATA TRANSMISSION TECHNOLOGIES

New generations of mobile networks (5G and 6G) should bring capabilities for reliable and highly energy-efficient low-latency operations. They enable resource-wise and energy-wise interconnected solutions.

STRONG CYBER-SECURITY

Sound cyber-security is fundamental to the digital solutions of the future. The energy sector is often a target of cyber-attacks, and further new challenges accompanying digitalisation may be expected. Secure future energy systems demand comprehensive attention to security, from the early stages of system design all the way to continuing operation.

[11] Source: Exponential Roadmap 1.5.1 (see Note 8).

EDGE INTELLIGENCE

The future systems represent balance between edge computing and centralised data centres, utilising both resources and the transmission systems intelligently and in an energy-efficient manner.

QUANTUM COMPUTING

Quantum computers should surpass digital computers by utilising quantum states instead of binary states. Hence, they should store and manipulate information efficiently and support hyper-advanced AI solutions, all to the benefit of a low-carbon society.

THE INTERNET OF THINGS

Smart devices collecting and reacting to data and connecting with digital platforms, digital twins, and advanced AI solutions offer an opportunity to unlock new levels of intelligence – e.g., with smart plug concepts – and IoT solutions are an essential element of versatile future energy systems.

ADVANCED ANALYTICS AND AI

Advanced artificial-intelligence solutions assist with the low-carbon society's adjustment to new inputs and tasks. They provide in-depth insight into optimisation of energy systems' supply and demand both, for industrial processes, energy use in buildings, and logistics.

DIGITAL PLATFORMS

Digital platforms simplify exchanging data, goods, and services. They encourage effective use of diverse energy resources and production portfolios and help add transparency and traceability to the markets.

DIGITAL TWINS

Digital twins enable managing dynamic information from multiple sources in real time. They support systemic understanding of complex energy systems, thereby generating greater energy-efficiency and better use of resources while also unlocking the power of such concepts as virtual power plants.

BLOCKCHAIN TECHNOLOGY

Blockchain technology facilitates virtual tracking and trading of assets in a low-carbon society. Decentralised energy transactions, metering and billing, and renewable-energy provenance can be handled in real time.

VIRTUAL AND AUGMENTED REALITY

Virtual- and augmented-reality systems promote efficiency in assembly and maintenance processes by assisting with analysis of real-time data input and providing guidance. They also enhance provision of versatile training and learning content for multiple system environments. Use of these solutions is already growing more common in developing energy systems.

3. GREAT PROMISE AT THE NEXUS OF DIGITALISATION AND ELECTRIFICATION

As the importance of digitalisation in general – and data transmission and data storage in particular – grows nearly exponentially, we must come to grips with this transformation. How to manage the following issues creates some of the and inter-sector integration of energy-consuming and energy-producing sectors, the continuous increase in data volumes and transmission, and cyber-security. Highly optimised energy solutions, smart infrastructure, and zero-emission data centres are key to managing the symbiosis of digitalisation and electrification (see Figure 2). These can bring CO_2 emission reductions to fruition, representing opportunities to gain significant cross-sectoral carbon leverage – that is, to exert a remarkable beneficial impact on carbon handprint while at the same time ensuring a contribution to reducing the carbon footprint of digitalisation.

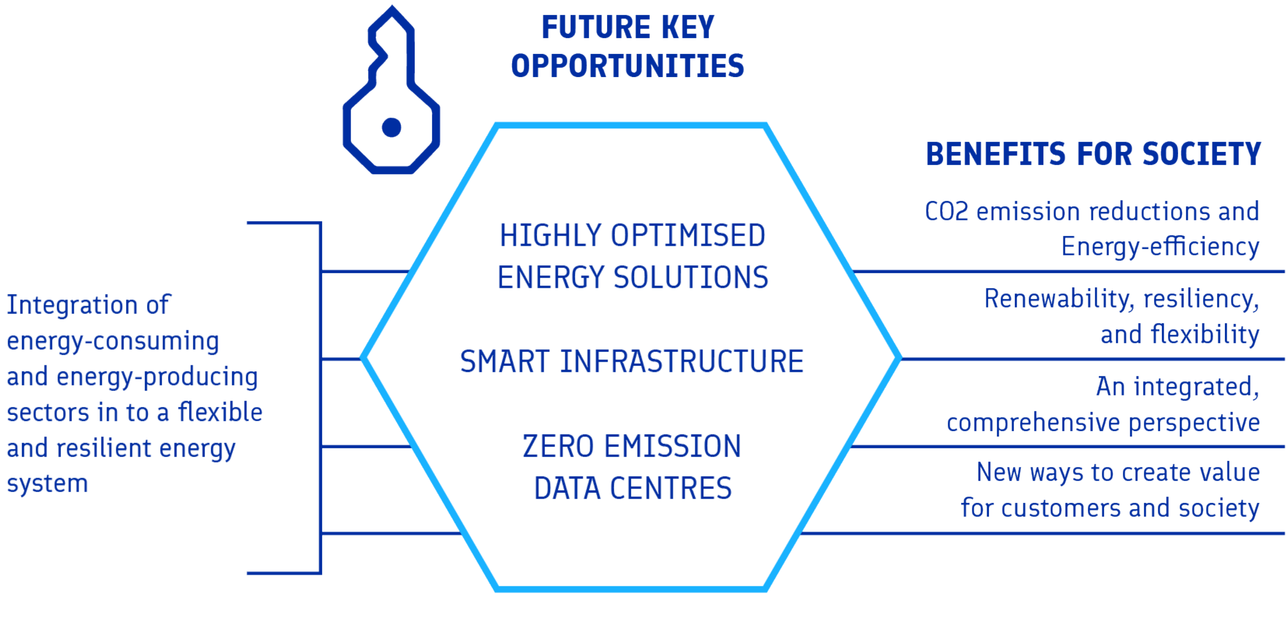

Figure 2. ***Key future opportunities and the benefits for society.***

THE CARBON HANDPRINT OF DIGITALISATION AND DATA

All over the world, companies and other organisations are finding new ways to decrease their climate burden. That impact is often measured in terms of the entity’s carbon footprint; however, there are many ways to make a positive impact on others’ carbon footprint too. Companies can express this impression in terms of the ‘carbon handprint’. The principle here is that a company develops products and services that help its customers to shrink their carbon footprint. Actions such as increasing their energy-efficiency, reducing the use of materials, making climate-friendly choices of raw material, advancing product recyclability, reducing the amount of waste material, extending products’ life span, and improving their usability all can contribute to a product's carbon handprint.

We can seize digitalisation’s potential to help reduce global carbon emissions by up to 15% – a full third of the 50% reduction required by 2030 – through solid solutions for energy, manufacturing, agriculture and land use, buildings, transportation, traffic management, and other services[12]. One of the keys to unlocking this potential lies in the contribution of digitalisation and data to optimising resource and energy use in these sectors. They can make a significant carbon handprint by supporting energy-efficiency improvements, de-materialisation and substitution, fuller use of renewable energy sources, and sharing of unused assets. Some concrete examples are investing in embedded vehicular systems for fuel-efficient driving, ‘smart’ electricity-distribution networks to reduce losses in transmission and distribution, and intelligent heating and lighting systems for buildings and urban environments[13].

Many factors in the systemic impacts of digitalisation and the data economy are rooted in how data-enriched decision-making informs human behaviour and promotes beneficial changes to it. The greatest impact hinges on end-user acceptance, lifestyle adjustments, and changes in collective social behaviour.

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[12] Source: Exponential Roadmap 1.5.1 (see Note 8).

[13] Source: International Institute for Sustainable Development. ‘Smarter and greener? Information technology and the environment: Positive or negative impacts?’, 2012.

3.1 Advanced energy solutions

Advanced energy solutions translate data into insight that supports decision-making. These solutions, summarised below in Figure 3, can incorporate demand response, take advantage of virtual power plants, and exploit AI and machine learning, also crystallising the power of mastering data platforms and disrupting old business models.

HIGHLY OPTIMIZED ENERGY SOLUTIONS

- Enable agile response to demand
- Take advantage of virtual power plants
- Exploit the opportunities of AI and machine learning
- Gain mastery of data platforms
- Disrupt prevailing business models

Figure 3. ***Data-driven insight actualised in advanced energy solutions.***

ENABLE AGILE RESPONSE TO DEMAND

Demand response gives consumers an active role in energy supply[14]. It is crucial for a flexible energy system that represents balance between decentralised production units and the customers. The global need for flexibility in 2050 is projected to be 10 times today's level. At present, less than 2% of the demand-side management potential is utilised[15]. Reaching demand response's full potential requires attention to such elements as virtual power plants and load aggregation.

Controllable loads could be utilised across the entire consumption spectrum, from industry, mobility solutions, and data centres to charging of electric vehicles. Just on its own, smart technology that helps shift vehicle-charging to times of low electricity demand and abundant supply would add considerable flexibility to the grid while saving anywhere from 100 to 280 billion USD on investments in new electricity infrastructure between 2016 and 2040[16]. Data centres' role in this system could involve, for example, uninterruptible power supply (UPS) systems and IT load management that adjusts the timing of non-urgent tasks.

[14] Source: 'Powering a climate-neutral economy' (see Note 12).
[15] Source: 'Demand response', from the Web site of the International Energy Agency, at https://www.iea.org/reports/demand-response (accessed on 25.1.2021).
[16] Source: 'Digitalisation and energy', from the Web site of the International Energy Agency, at https://www.iea.org/reports/digitalisation-and-energy (accessed on 25.1.2021).

TAKE ADVANTAGE OF VIRTUAL POWER PLANTS

Virtual power plants contribute to clean-energy systems by connecting local renewable production, storage capacity, and controllable loads on the demand side with large-scale energy-transmission and production systems. Whether involving high-capacity, megawatt-scale virtual power concepts or embodying multiple smaller-scale solution aggregations, virtual power plants provide flexibility and enable raising the profile of renewables in the overall system. Digitalisation and data enable aggregating, controlling, monitoring, and optimising the system.

EXPLOIT THE OPPORTUNITIES OF AI AND MACHINE LEARNING

Modern AI and machine-learning solutions possess vast potential for system optimisations, improvements in energy-efficiency, and generation of forecasts and predictive actions. Artificial intelligence in general can yield new insights for improvement of the energy system (e.g., via enhanced forecasting models), and machine learning brings the power of continuously self-updating algorithms that analyse and operate diverse energy solutions.

AI holds immense promise for the energy sector. Already, it is expected to bring significant energy-efficiency improvements to all branches of industry in the near future. For example, Google has effectively used AI to reduce data centres' cooling-energy consumption by 40%[17]. It should not be surprising, then, that utilising AI to improve the operation and maintenance of renewable energy production is gaining currency[18].

GAIN MASTERY OF DATA PLATFORMS

Mastering the energy markets and energy production of the future and guaranteeing system flexibility and energy-efficiency for our many industries requires smooth data flows. Advanced data platforms synthesise versatile systems that meet this need by compiling all the relevant energy-related data from these numerous sources. Platform activities afford sharing of information among asset-owners, operators, regulators, and investors while not interfering with network operation.

DISRUPT PREVAILING BUSINESS MODELS

Data platforms and hubs used in combination with smart metering and IoT-enabled devices facilitate new operators' market entry. Diversity grows as they bring different business models and alternative energy-resource and production portfolios to the table. In addition, sharing data along the whole value chain brings huge opportunities for traceability and life-cycle assessment of the various energy solutions.

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[17] Source: 'Exploring the impact of AI in the data center', from *Forbes* online, at https://www.forbes.com/sites/cognitiveworld/2019/05/31/exploring-the-impact-of-ai-in-the-data-center (accessed on 11.2.2021).
[18] Source: 'Improving wind-turbine O&M with artificial intelligence', from the Web site of Windpower Engineering & Development, at https://www.windpowerengineering.com/improving-wind-turbine-om-with-artificial-intelligence/ (accessed on 25.1.2021).

EXAMPLE SOLUTIONS ALREADY IN USE

Virtual power plants: A virtual-power-plant service has been implemented for a shopping centre. The solution is based on a 550-kilowatt peak solar panel system, intelligent LED lighting, and about 2 MW of electricity-storage capacity connected to a micro-grid. An advanced energy unit enables control of the electricity purchasing, consumption, storage, and smoothing of demand spikes in the national grid. Details are available at https://new.siemens.com/global/en/company/stories/infrastructure/2020/sello-virtual-power-plant.html.

An AI-driven energy supply: AI adds intelligence to district heat production in Helsinki. This intelligent application brings the planning of district-heating production as close as possible to the actual demand, through a machine-learning solution. It makes use of historical reports in addition to weather and time-related data, adapting to new data. Information can be found at https://silo.ai/helen-and-silo-ai-bring-intelligence-to-district-heating-production-in-helsinki/.

Micro-grids: A system integrating micro-grid and building-operation solutions delivers high energy-efficiency and completely renewable energy usage for facilities management. This system uses a micro-grid comprising an energy-storage solution supported by an application that collects, forecasts, and optimises on-site resources' operation by means of real-time data and predictive machine-learning algorithms. The system enables the excess heat from the cooling to be stored and used when the weather gets colder. For further information, see https://www.se.com/ww/en/work/campaign/life-is-on/case-study/lidl-finland.jsp.

Energy-data platforms: Uniform trading in the Elbas system balances the power market, thanks to creation of a suitable platform. Describing the desired modifications on this platform enables new operations' optimisation and the enhancement of the trading algorithms. The trading robot connected with the platform acts in the electricity market to offset fluctuations in actual consumption. Details are presented at https://www.wapice.com/customers/cost-effective-and-uniform-trading-in-elbas-balancing-power-market.

3.2 Smart infrastructure

The smart infrastructure of the future brings together digital and energy infrastructure. This integrated infrastructure builds on new modes of data transmission, circular energy systems, and smart urban infrastructure. In addition, the solutions integrate micro and macro systems, encompass hybrid energy systems, and support flexible conversion of energy alongside cross-sector energy storage (see Figure 4, below).

SMART INFRASTRUCTUR

- Transform data transmission
- Build circular systems
- Design smart urban infrastructure
- Integrate micro and macro systems
- Build on hybrid energy systems and lexible conversion of energy
- Exploit cross-sectoral energy storage

Figure 4. ***Smart infrastructure synthesising digital and energy frameworks.***

TRANSFORM DATA TRANSMISSION (VIA 5G AND 6G)

By enabling almost limitless connectivity for the coming application and services, future data transmission will revolutionise how societies and industries function[19]. The data transmission of the future creates conditions for clean-energy communities by ensuring sufficient data transmission for all of the various AI-controlled processes, such as advanced industrial automation and building-management systems.

New generations of mobile networks promise reliability and low latency simultaneous with high energy-efficiency. Thus, we can escape the upward curve in energy consumption from data transmission. Relative to 4G technology, 5G enables 100 times more traffic with the same energy consumption or even less[20]. Factors in the improved energy-efficiency of data transmission are high-spectrum-efficiency antennas, wider band-width, power-saving mechanisms for base stations, features that

save energy outside peak hours, improved cooling techniques such as liquid-cooling systems, and general advances in the efficiency of data transmission[21]. It is estimated that transmission by data networks consumed around 250 TWh of electricity in 2020 alone, with the annual total forecast to reach around 600 TWh

[19] Source: 'Ever-present intelligent communication: A research outlook towards 6G', from the Ericsson Web site, at https://www.ericsson.com/en/reports-and-papers/white-papers/a-research-outlook-towards-6g (accessed on 11.2.2021).
[20] Source: Nokia. 'How 5G is bringing an energy efficiency revolution'. White paper, 2020.
[21] Ibid.

in 2030[22]. Data transmission is responsible for nearly 1% of all the world's electricity consumption[23].

BUILD CIRCULAR ENERGY SYSTEMS

Circular energy systems are designed for maximally efficient use of natural resources, optimal end use of energy, and the utilisation of any excess energy generated and other side or waste streams. They also enable efficiencies in upstream energy production by giving priority to the least energy-intensive choices, putting unavoidable waste streams to use for energy purposes, and exploiting synergies across sectors[24]. Digitalisation and data are crucial enablers of circular strategies, involving renewable energy, waste-to-energy solutions, fuel conversion, utilisation of excess energy and side streams, demand response, energy-as-a-service approaches, and energy-efficiency for the end user through inclusive digital platforms.

DESIGN SMART URBAN INFRASTRUCTURE

Digital solutions have a significant role to play in cutting the emissions originating from the built environment, through their potential in Big Data accumulation and analysis, energy-efficiency improvements, optimisation of material use, and enhancements to end-user-driven circular economy via digital platforms. Smart residential- and commercial-building-level applications act alongside advanced industry applications, such as digital twin and 3D modelling technologies, to test and optimise energy flows both in narrower, building-level systems and in wider contexts, such as designing smart cities.

ICT solutions employed for energy-efficiency and mobility are extensively interlinked in the context of the built environment and urban planning for smart cities. Data centres, as part of the framework of the built environment, can be established within existing infrastructure that supports energy-efficiency and accessibility. The built environment can be considered a platform itself, where physical assets and human action are interconnected through digital solutions and further platforms.

INTEGRATE MICRO AND MACRO SYSTEMS

An integrated energy system implies a decentralised grid in which energy flows freely between consumers, producers, and storage solutions. It requires 'reverse flows' of energy, from distribution to transmission entities. That means connecting the electricity and gas networks in a hybrid system. At both local and European level, smart electricity and smart thermal grids enable flexibility and choosing both the most cost-effective forms of renewable energy and the best uses for them, across the bound-aries of sectors, applications, time, and space.

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[22] Source: Anders S.G. Andrae, 'Hypotheses for primary energy use, electricity use and CO_2 emissions of global computing and its shares of the total between 2020 and 2030'. *WSEAS Transactions on Power Systems* 15 (2020): 50–59.
[23] Source: 'Digitalisation and energy' (see Note 18).
[24] Source: 'Powering a climate-neutral economy' (see Note 12).

By enabling data-processing close to the data source, edge computing reduces latency and the amount of data transmission[25]. Pressure for low

latency, short execution times, reliability, and data security is driving edge computing forward. At present, 80% of the processing and analysis of data is still performed at data centres and centralised computing facilities, while 20% is handled by computing facilities closer to the edge.

BUILD ON HYBRID ENERGY SYSTEMS AND FLEXIBLE CONVERSION OF ENERGY

The future will see co-ordination of energy supply and demand across multiple energy-carriers and infrastructural settings[26]. Enhanced by flexible conversion between energy sources, these solutions build on hybrid energy systems and new clean energy-carriers. Already, smart hybrid infrastructure and power-to-heat, power-to-gas, power-to-mobility, and other power-to-*x* solutions are all rendering energy systems more efficient[27]. Rapid electrification of end-use sectors is under way, with vast potential for use of renewable and low-carbon fuels (including hydrogen) in end-use applications wherein direct heating or electrification is infeasible, inefficient, or prohibitively expensive. Further exploiting synergies of the electricity sector, the gas sector, and end-use sectors, solutions based on renewable gases and liquids produced from biomass or renewable, low-carbon hydrogen can be developed for storing energy produced from a host of renewable sources,[28].

EXPLOIT CROSS-SECTORAL ENERGY STORAGE

The future energy landscape showcases optimised utilisation of both power and storage systems alongside stability for the grids. Both aggregation of controllable devices for demand response and virtual-power-plant concepts are important elements for stabilising the grids. The ability to optimise such a versatile system with the necessary storage opportunities and minimisation of gaps between production and demand requires active data flow between systems, sufficient processing capacity, and accurate forecasts. Here, opportunities created by the distributed storage capacity of millions of home and car batteries represent vast untapped potential.

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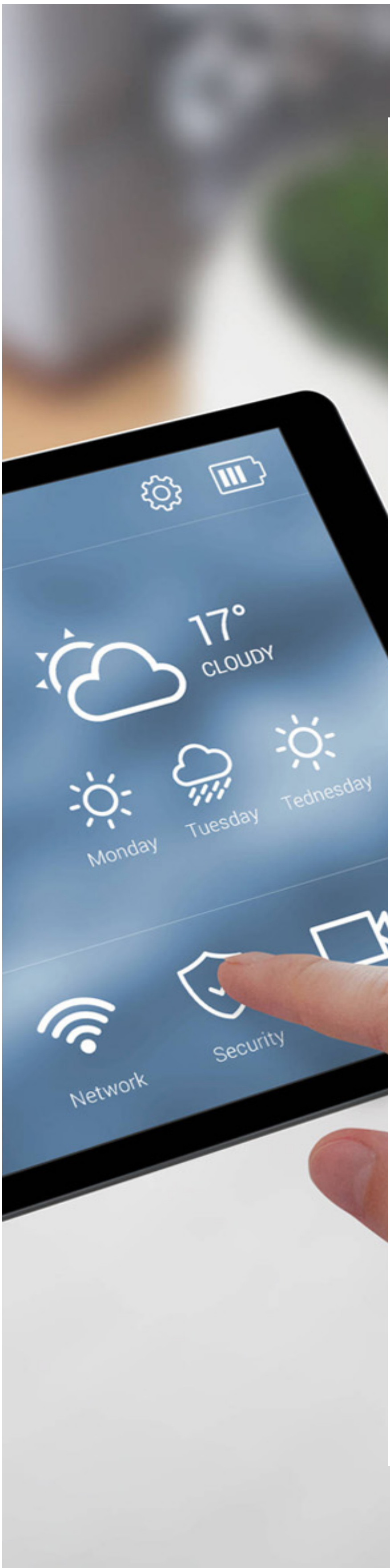
[25] Source: Sustainable Digital Infrastructure Alliance. 'The utility of the future: Where digital and energy infrastructure combine', 2020.
[26] Source: 'Powering a climate-neutral economy' (see Note 12).
[27] Source: 'The role of sectoral integration in the clean energy transition' at the World Future Energy Summit, Abu Dhabi (ADNEC Capital Suites 1 & 2), 14.1.2019.
[28] Source: 'Powering a climate-neutral economy' (see Note 12).



EXAMPLE SOLUTIONS ALREADY IN USE

Future data transmission: 5G and 6G systems offer almost limitless connectivity for upcoming digital applications and services. At the same time, they can break the rising curve of energy consumption from data transmission. Sustainable, circular design is already being designed and applied for new generations of technology solutions and mobile networks. Additional information can be found at https://www.nokia.com/networks/5g/building-sustainable-5g/ and https://www.ericsson.com/en/reports-and-papers/white-papers/a-research-outlook-towards-6g.

Low-latency smart electricity grids: A successful trial has implemented one of the first real-world applications of time-critical 5G applications for smart electricity grids and harbour automation. The system demonstrates how ultra-reliable low-latency communication technology can be employed to protect a production medium-voltage distribution network. Further information is available at https://www.cargotec.com/en/nasdaq/trade-press-release-kalmar/2018/nokia-abb-and-kalmar-conduct-industrys-first-trial-with-ultra-reliable-low-latency-5g-technology-for-electricity-grid-and-harbor-automation/.

Solid energy management for facilities: IoT-driven smart building control and maintenance solutions already are in place, resulting in energy-efficiency, lower peak power demand, and a better indoor environment. One solution for intelligent management of buildings is based on building heating system control with artificial intelligence and flat-specific sensors. For details, see https://leanheat.com/.

Storage systems that support grid stability: An accumulator unit the size of a shipping container improves the reliability of electricity distribution and the supply quality for Inkoo, Finland. The accumulator-based storage, connected to the municipality's medium-voltage network, is part of a smart electricity network deployment. Information is provided at https://www.caruna.fi/en/news/accumulator-storage-fortum-and-caruna-improves-reliability-electricity-system.

3.3 Zero-emissions data centres

The zero-emission data centres of the future are highly energy-efficient facilities that recycle waste heat well and take advantage of demand response. They are integrated with the energy system and utilise renewable sources. Figure 5 provides a summary.

ZERO-EMISSION DATA CENTRES

- Share foundations with the energy system
- Use renewable energy
- Employ highly energy-efficient methods
- Recover waste heat
- Take advantage of demand response

Figure 5. ***Highly energy-efficient data centres, for a low-emission future.***

SHARE FOUNDATIONS WITH THE ENERGY SYSTEM

Through full integration with the larger energy system, data centres can provide recycled heat and offer flexibility for grids. A potentially valuable component in smart grids and local heating systems, they should be considered in the planning of low-carbon urban infrastructure. For example, many countries could exploit existing district-heating infrastructure for recycling of waste heat.

USE RENEWABLE ENERGY

The zero-emission data centres of the future are connected to electricity grids supplied by 100% renewable energy sources. In addition, the data centres may implement on-site renewable energy production of their own, to support local zero-emission grids.

EMPLOY HIGHLY ENERGY-EFFICIENT METHODS

A shift to ever more efficient data centres can help reduce the demand for electricity even amid the exponential growth of data management[29]. Centralised hyper-scale data centres can replace inefficient smaller data centres, thereby improving overall energy-efficiency. Data centres' energy-efficiency is further supported by smart cooling and quantum computing. Future data centres will rely in particular on liquid cooling. Liquids whose heat-transfer properties greatly surpass those of air enable highly efficient cooling systems[30]. The effectiveness of liquid cooling does depend on the location of the data centres, with sites in warm locations holding more potential. That said, facilities in cold climates improve cooling systems' efficiency by eliminating the need for chiller compressor power.

[29] Source: 'Data centres and energy – from global headlines to local headaches?', from the Web site of the International Energy Agency, at https://www.iea.org/commentaries/data-centres-and-energy-from-global-headlines-to-local-headaches (accessed on 25.1.2021).
[30] Source: 'Liquid cooling', from the Web site of the Center of Expertise for Energy Efficiency in Data Centers, at https://datacenters.lbl.gov/technologies/liquid-cooling (accessed on 25.1.2021).

Developments in quantum computing should bring highly efficient storage and manipulation of information. By many accounts, quantum computers will require only a hundredth of the energy needed by a digital super-computer today, thanks to memory that uses quantum states instead of traditional binary states[31].

RECOVER WASTE HEAT

A data centre can serve as a local energy provider, by feeding the surplus heat produced to an area district-heating network. Typically, data-centre operations release significant waste heat into the surrounding air or water through free cooling[32]. Output temperatures of the liquid coolants used at data centres are steadily approaching the input temperature for district heating[33] – currently, the waste-heat temperature is around 50 °C and the level for input to district heating varies within the 75–120 °C range. Low-quality heat sources could be brought to the required level by heat-pump systems. Clearly, waste-heat recovery systems hold huge potential for CO_2 emission reductions.

PRODUCE BENEFITS BY RESPONDING TO DEMAND

Data centres can facilitate energy-grid stabilisation by scheduling tasks for off-peak hours. This already supports grid integrity at peak hours but can be taken further, by shifting and allocating the tasks in time and space amongst a cloud federation of data centres[34]. This resolves local grid constraints and balances the national grid. Also, UPS systems at data centres can function for grid stabilisation. A modern UPS system draws power effectively from the grid as needed or supplies power from its batteries in response to the grid's voltage and frequency variations[35,36].

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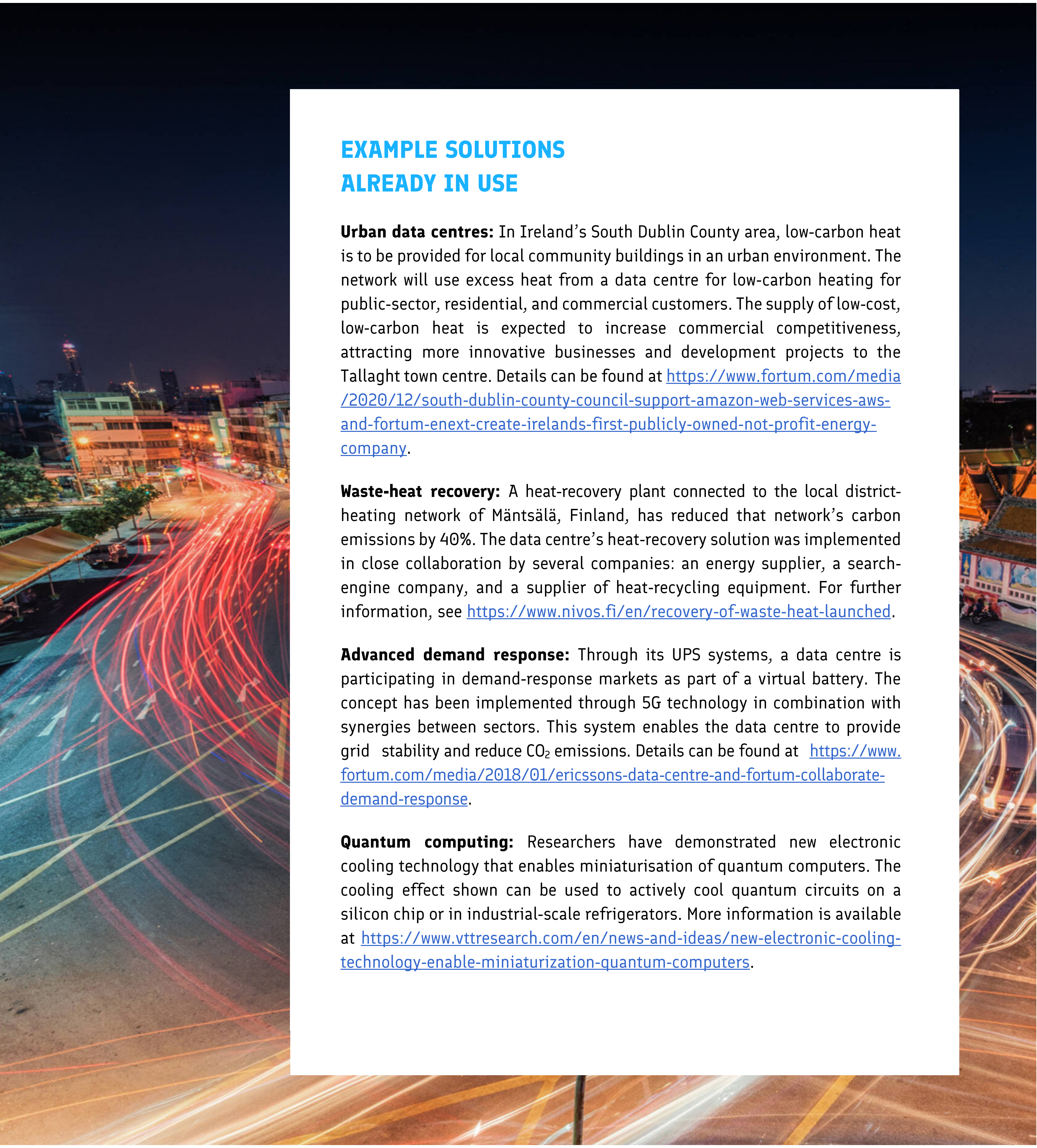
[31] Source: Finnish Ministry of Transport and Communications. 'The ICT sector, climate and the environment: Interim report of the working group preparing a climate and environmental strategy for the ICT sector in Finland'. Finland, 2020.
[32] Ibid.
[33] Source: 'The utility of the future' (see Note 27).
[34] Ibid.
[35] Source: 'Put your UPS to work generating new revenue', from the Data Center Frontier Web site, at https://datacenterfrontier.com/ups-eaton-new-revenue-data/ (accessed on 27.1.2021).
[36] Source: 'The utility of the future (see Note 27).



EXAMPLE SOLUTIONS ALREADY IN USE

Urban data centres: In Ireland's South Dublin County area, low-carbon heat is to be provided for local community buildings in an urban environment. The network will use excess heat from a data centre for low-carbon heating for public-sector, residential, and commercial customers. The supply of low-cost, low-carbon heat is expected to increase commercial competitiveness, attracting more innovative businesses and development projects to the Tallaght town centre. Details can be found at https://www.fortum.com/media/2020/12/south-dublin-county-council-support-amazon-web-services-aws-and-fortum-enext-create-irelands-first-publicly-owned-not-profit-energy-company.

Waste-heat recovery: A heat-recovery plant connected to the local district-heating network of Mäntsälä, Finland, has reduced that network's carbon emissions by 40%. The data centre's heat-recovery solution was implemented in close collaboration by several companies: an energy supplier, a search-engine company, and a supplier of heat-recycling equipment. For further information, see https://www.nivos.fi/en/recovery-of-waste-heat-launched.

Advanced demand response: Through its UPS systems, a data centre is participating in demand-response markets as part of a virtual battery. The concept has been implemented through 5G technology in combination with synergies between sectors. This system enables the data centre to provide grid stability and reduce CO_2 emissions. Details can be found at https://www.fortum.com/media/2018/01/ericssons-data-centre-and-fortum-collaborate-demand-response.

Quantum computing: Researchers have demonstrated new electronic cooling technology that enables miniaturisation of quantum computers. The cooling effect shown can be used to actively cool quantum circuits on a silicon chip or in industrial-scale refrigerators. More information is available at https://www.vttresearch.com/en/news-and-ideas/new-electronic-cooling-technology-enable-miniaturization-quantum-computers.

THE CARBON FOOTPRINT OF DIGITALISATION AND DATA

Digital technologies' energy consumption, from the equipment's manufacture and its use, is increasing by 9% a year and already represents 4% of global greenhouse gas emissions[37]. According to estimates for 2020, today's data centres consume around 300 TWh of electricity per year and emit 160 Mt of CO_2[38]. Data transmission, in turn, is estimated to have consumed around 250 TWh of electricity in 2020 and produced 140 Mt of CO_2[39], with mobile networks representing 40% of that consumption figure and optical networks 60%[40]. Currently, the energy use of consumer devices represents the largest share of the ICT sector's energy consumption. It is estimated that they accounted for a full 50% of that sector's total electricity use in 2020, coming to 830 TWh[41] of electricity consumed. The remaining 300 TWh of the ICT sector's electricity consumption arises from manufacturing of digital equipment[42].

The impact of digitalisation and the data economy on energy demand is significant. Therefore, it is essential to continually improve the energy-efficiency of ICT solutions, seize opportunities for waste-heat recovery, and maximise the role of a carbon-free energy supply for computation work, thereby diminishing the ICT carbon footprint. In addition, diverse demand-response solutions can reduce ICT systems' burden on the environment while offering flexibility for the grids and permitting a larger share of renewable production in the energy supply. Energy-efficiency is best supported by ICT infrastructure that is deeply integrated into the fabric of society as a whole, including the energy infrastructure. Thus, we can get the most from the synergies produced (for example, in heat production).

The future energy consumption of digitalisation and data will be determined by the race between exponential growth of Internet traffic and advances in the energy-efficiency of ICT systems.[43] In addition, the share of renewables in energy production has an enormous effect on carbon footprints.

[37] Source: 'Lean ICT' (see Note 4).
[38] Source: 'Hypotheses for primary energy use' (see Note 24).
[39] Ibid.
[40] Ibid.
[41] Ibid.
[42] Ibid.
[43] Source: 'Digitalisation and energy' (see Note 18).

This factor is especially significant in light of forecasts suggesting that the ICT sector will be responsible for 21% of global electricity demand by 2030.[44] Data centres and data transmission are expected to show a rapid rise in energy consumption, while the energy consumption of device use and manufacturing of digital equipment is projected to take a downward turn by 2030. Figure 6 presents a breakdown of the global electricity-consumption forecasts for the ICT sector, and Table 2 addresses developments in the future energy use and CO_2 emissions originating from data centres, data transmission, and user devices.

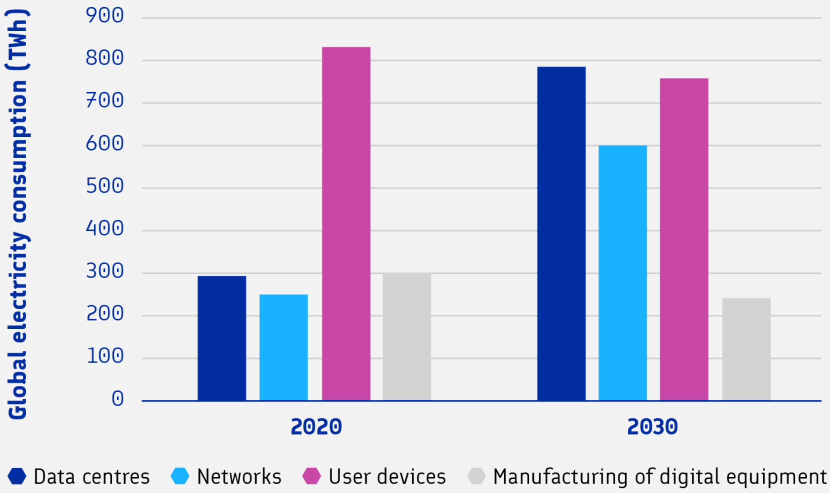


Figure 6. ***Global electricity consumption of data centres, networks, user devices, and manufacturing of digital equipment, for 2020 and projected to 2030.***[45]

[44] Source: Nicola Jones. 'How to stop data centres from gobbling up the world's electricity', from the *Nature* Web site, at ttps://www.nature.com/articles/d41586-018-06610-y (accessed on 11.2.2021).
[45] Source: 'Hypotheses for primary energy use' (see Note 24).

Table 2. ***Future energy use and CO2 emissions of data centres, data transmission, and user devices***

	FUTURE ENERGY USE AND CO_2 EMISSIONS	FACTORS AFFECTING THE FUTURE CARBON FOOTPRINT
DATA CENTERS	The electricity consumption of data centres has been estimated at around 300 TWh globally for 2020 and projected to reach nearly 800 TWh in 2030.[46] On the same time horizon, CO_2 emissions are forecast to increase by 163% from their 2020 level of 160 Mt[47].	Data centres require vast amounts of electricity, to power numerous servers and network devices. The power that data-processing consumes gets converted into heat, which needs to be removed efficiently. Hence, cooling systems account for the majority of data centres' energy consumption, amounting to 10–100% of their total energy demands. Relatively minor energy demands at data centres are created by facility lighting, ventilation, heating, maintenance, and control-room and office work.[48] Future data centres' burden on the environment is highly dependent on these facilities' energy-efficiency, the waste-heat recovery possibilities, implementation of suitable demand-response systems, and the data-processing efficiency enabled by advances such as quantum computing.
DATA TRANSMISSION	Estimates put the total electricity consumed by transmission over data networks at around 250 TWh globally for 2020 alone. Two fifths of this electricity was consumed by mobile networks. Consumption is projected to rise to roughly 600 TWh by 2030, with CO_2 emissions expected to grow by 112% from the value of 140 Mt reached in 2020[49]; however, developments will greatly depend on data-transmission efficiency. This highlights the potential for data-transmission-related energy-efficiency measures[50].	Generally, networks' largest environmental impact is from their in-use energy consumption. Experts found that around 93% of the calculated lifetime carbon dioxide emissions of mobile networks is generated in their use, 7% from manufacturing, and 1% from logistics.[51] It proves tricky to analyse communication networks' energy-consumption and energy-efficiency development, because of inconsistent data-collection practices and a lack of statistics. It does appear that, in general, fixed networks are more energy-efficient than mobile ones, though the energy-efficiency of mobile networks is rising rapidly. The electricity consumption of the latter came to around 1.6 kWh/GB in 2014 and had fallen to 0.3 kWh/GB in 2018. The standardisation work for 5G mobile data transmission is aimed at improving the energy-efficiency by a factor of 100 (in terms of joules/bit) from that of today's top-standard 4G technology. While future efficiency seems promising, the effects on total energy consumption remain unclear since 5G requires a denser base-station network than 4G does.[52]

[46] Ibid.
[47] Ibid.
[48] Source: 'The ICT sector, climate and the environment' (see Note 33).
[49] 'Hypotheses for primary energy use' (see Note 24).
[50] Source: 'Digitalisation and energy' (see Note 18).
[51] Source: 'The ICT sector, climate and the environment' (see Note 33).
[52] Ibid.

USER DEVICES

It is estimated that user devices consumed 830 TWh of electricity in 2020 globally[53]. While modern devices' energy-efficiency is rising, the number of small devices and home appliances is growing[54]. Still, user devices' energy consumption is forecast to decline slightly by 2030, thanks to energy-efficiency[55], with CO_2 emissions expected to show a corresponding reduction, of 11% from 2020's figure of 450 Mt[56].

For user devices, around half of the total carbon footprint comes from the devices' own energy use and the other half from their life cycle[57]. The main reason for these devices' predicted decline in energy consumption is an expected shift away from laptop and desktop machines in favour of efficient tablet computers and smartphones, which should reduce overall power use significantly[58]. The sector's energy consumption is concentrated predominantly in data centres and energy transmission.[59] End users' role is growing through edge computing and demand response, enabled by smart-plug concepts in both the ICT and the energy sector.

4. THE WAY FORWARD

Digitalisation and electrification are the main drivers in the move toward a low-carbon society. In symbiosis, they propel a process of transformation into a climate-friendly energy system. Importantly, this interaction does not leave the energy-users behind: it enables a new role for them in producing and storing energy. As well, it allows for a rapid increase in the percentage of energy use covered by renewables. These developments should culminate in a positive system-level change that turns the vision of a low-carbon society into reality.

Such future developments require seamless co-operation among a variety of actors and extensive integration of systems. Finland can be in the vanguard in this respect – it represents an excellent platform for development and strategic partnerships that cover all elements of the necessary evolution: pursuit of the ambitious goal of being carbon-neutral by 2035; and an acknowledged position as a forerunner in technologies, solutions, know-how, and ecosystems for strong collaboration. To unlock digitalisation's power for creating truly substantial positive carbon leverage, the following actions are critical.

[53] Source: 'Hypotheses for primary energy use' (see Note 24).
[54] Source: 'The ICT sector, climate and the environment' (see Note 33).
[55] Source: 'Hypotheses for primary energy use' (see Note 24).
[56] Ibid.
[57] Source: 'Exponential data growth – constant ICT footprints', from the Web site of Ericsson, at https://www.ericsson.com/en/reports-and-papers/research-papers/the-future-carbon-footprint-of-the-ict-and-em-sectors (accessed on 25.1.2021).
[58] Source: 'Hypotheses for primary energy use' (see Note 24).
[59] Source: 'The ICT sector, climate and the environment' (see Note 33).

CREATE NEW PARTNERSHIPS

Innovation takes place in networks wherein all actors work in close co-operation. Trust is a vital component of networks, as co-creation is ultimately a matter of people-to-people collaboration. Inevitably, new value networks will force organisations to reconsider their value-creation logic and introduce new business models. In this context, the opportunity for co-creation must be prioritised on the European agenda.

ACT FOR INNOVATION-FRIENDLY REGULATION

Appropriate regulation is one of the best ways to encourage investment in a digital energy system. Innovation-friendly regulation opens opportunities for new services and for lean, efficient energy systems that support sectors' integration. In the longer term, it encourages systemic changes in which data-sharing and new business models play a key role. To flourish, the EU needs a forward-looking, competitive regulatory environment.

EMPOWER FLUENT DATA FLOWS

Exploring, managing, and sharing data flows between actors and across markets empowers the development of future solutions. Data availability, quality, and management are crucial. Creating a shared, level playing field demands open data ecosystems and appropriate standards and interfaces in particular.

ENSURE CYBER-SECURITY

Cyber-security plays a key role in critical infrastructure. Secure future energy systems demand comprehensive attention to security, from the early stages of system design all the way to continuing operation. More generally, strong soft infrastructure is needed to drive development forward and all actors are needed to address this challenge.

DISCOVER NEW EXPERTISE

New expertise is needed at the confluence of digitalisation and energy – at all levels of education and in working life. According to a survey of business leaders around the world, 46% of businesses are already furthering their in-house digital skills and talent. Both public and private investments are vital for ensuring that the future expertise necessary gets developed and deployed.

BUILD SYSTEMIC CHANGE

The development of new solutions has to be holistic and drive systemic change. For the seamless interoperability of systems and smooth interfaces this entails, comprehensive systems – not merely bits and pieces of them – have to be developed, in cross cutting innovation ecosystems. Action must follow the research investments: piloting and demonstration, leading to scalable industrial solutions.

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